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Abstract

A cost effective fiber optic uplink for video information has been designed and successfully tested in a shallow water (i.e. $\leq$ 20 meters) environment. The camera and transmitter are operated within a diver held underwater light housing. A novel fiber optic housing penetrator has been designed and tested down to a depth of 1200 meters. The receiver on the surface can drive a monitor or video tape recorder. As tested the system provides ample margin for much longer link distances. Quantitative information (e.g. heading or depth) can be superimposed on the video data for display. A preliminary design expanding the link to include a bidirectional capability allowing a lower frequency (control data) downlink is also discussed.

Introduction

The applications of underwater television run from deep submergibles to off-shore platform inspection to torpedo recovery by the Navy. Perhaps the most routine use is underwater hull inspection of ships. Recent strides in electronics have miniaturized the cameras and the power required. Current technology however still uses coaxial cables for transmitting the information to the surface. With increased depth however the attenuation and weight requirements of coaxial cable imposes a severe weight penalty. Representative underwater TV cables have an overall diameter of 1.25 cm and a weight in air of 1.73 kg/meter. The underwater weight is typically 1.01 Kg/m. Single armor coaxial cable typically is twice as big in diameter and weighs four times as much.

Fiber optic cable however offers the potential of a large bandwidth channel with less weight and smaller diameter. While presenting other problems to the cable designer such as lower strength, nonstandard connections, and high pressure effects, the weight and size savings offered by fiber technology promised enough to merit further study. A simple fiber cable can be .5 mm in diameter and can weigh 5.1×10^{-4} Kg/m. This paper reports on a prototype design and testing results of a fiber optic video uplink for underwater use. The study sought to identify system tradeoffs, to determine hardware feasibility and to measure system performance in an underwater test.

System Requirements

Figure 1 shows a representative bidirectional link that might be required for a television directed remote underwater vehicle. Various devices on the vehicle are controlled by the downlink while sensor and video information are combined in the uplink for presentation to the operators at the surface. Because the bandwidth requirements on the uplink are more severe, it was decided to implement that link rather than the less taxed downlink.

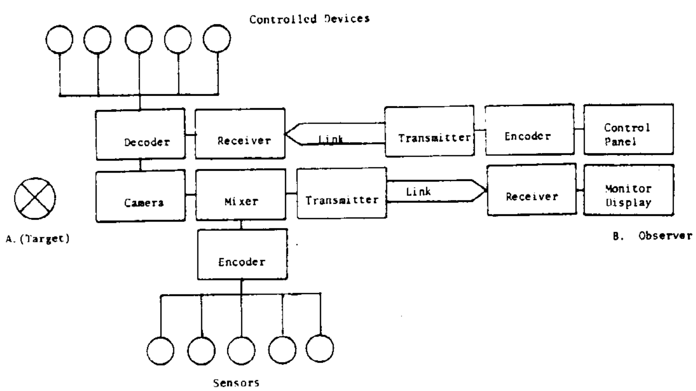


Figure 1. Block diagram of bidirectional video link

In the underwater portion of the link the electronic and optical elements were considered to be mounted in a pressure housing. An electronic-to-optical convertor would also be enclosed. The video and data information would be electronically mixed before being converted to optical signals. Because of the pressure housing it was necessary to consider a bulkhead penetrator. This penetrator allows the optical fiber to enter the housing while resisting leakage at high pressures. The system was conceived for operation for short durations (up to six hours) so a local power source on the vehicle was assumed eliminating power transmission requirements.

The surface portion of the uplink does not require a pressure-proof housing hence is much simpler. An optical-to-electronic convertor is required along with a television monitor and recorder to display and record the results. As implemented the sensor data would be digitally superimposed on the monitor screen in a convenient location.

The designed operational length of the uplink was 1 Km allowing convenient operation down to 600 m. The pressure housing and bulkhead penetrator were required to work down to this depth. The video signal from the camera into the monitor was a 1 v pk-pk NTSC standard composite video signal with 5 MHz bandwidth. The required signal-to-noise ratio (SNR) of 30-40 dB at the monitor produced high quality video images. It was desired that the total system for the uplink should weigh less than 70 Kg and that the cost should be less than $1500.

The engineering design began with a link analysis comparing source and receiver combinations with representative fiber attenuations. The analysis showed that for simplex unidirectional communication most LED sources and PIN diodes could be used successfully with 5 dB/Km fiber. For full duplex communications using bidirectional couplers with a typical total (i.e., device and detector) insertion loss of 4 dB each, the more powerful LED sources (e.g., the Spectronics SE 3352 or the Laser Diode IRE 160FB) could also work but that the safety margin in the calculations was reduced. Longer bidirectional links would require some combination of more powerful source, more sensitive detector and/or lower loss fiber. The relatively low bandwidth of 5 MHz presented no speed problems for either the sources or the receivers and, of course, was no problem for the fibers over this distance.

The choice of a suitable underwater cable is severely limited by the current lack of commercial underwater fiber cables. The prime advantages of fiber optics is the wide bandwidth combined with light weight. In two other areas of performance, tensile strength and enduring environmental effects, further design and testing are necessary. The strength of fiber alone is not enough for most underwater applications. Localized flaws cause cracks whose growth is accentuated by temperature, applied strain and moisture. While temperature gradients are minimized in an underwater environment, the fibers used in underwater cables require external strength members and isolation from the water and its vapor. For strength members lightweight materials such as Kevlar and S-glass have proven useful in underwater prototypes [1]. Heavier cables can use high strength steel rocket wire. If power conduction is required of a light weight cable, aluminum (used with light weight strength members) offers advantages. Heavier cables can use copper-clad steel. The use of switching power supplies in a vehicle with a power line can decrease electrical losses in the cable. To keep water away from the fiber metal-covered glass fibers have been attempted with mixed results [2]. Recent work with cables filled with polybutene jelly have also proven relatively successful [3]. The status of underwater cabling can best be improved by engineering development. There seem to be no technological impediments. Reference [1] contains the encouraging results of tests on underwater cable prototypes performed by the Naval Ocean Systems Center, Hawaii, in its effort to develop military standards and tests for underwater cables.

Prototype Link

Camera. The camera used was a Quasar VK105QE black-and-white camera. Its specifications are shown in Table 1. An optional adapter allows operation of the camera from a

Table 1. Quasar VK105QE Camera Specifications

Model:	Quasar VK105QE
Type:	Black and white
Power Consumption:	6 watts
Minimum Illumination:	5 ft.-candle with F 1.6 lens automatic light compensation 5 - 10,000 ft.-candles (1:2000)
Video Output:	1 v p-p 75 ohm (neg sync)
Synchronizing:	2:1 interlace
TV System:	EIA standard 60 fields 525 lines
Signal to Noise:	More than 40 dB
Weight:	1.98 lbs.

12 volt DC supply and was used in this link. In order to fit into the underwater housing the camera was modified removing the case and disabling its remote control feature and microphone. The vidicon tube and mount were separated from the camera's circuit boards for packing into the housing. Since the camera focus cannot be changed while in the housing, a fixed focal length of approximately 1.5 m was selected giving a usable depth of field of approximately 3 meters.

Character generator. Digital uplink data can be superimposed on the picture using integrated circuits that are normally used to display time and channel information on commercial sets. A National MM 5841 character generator and supporting circuitry were used as shown in Figure 2 to add simulated data to the display. Synchronizing information is derived from the Sony CX145 sync separator chip. The user is able to place the data in any useful location on the screen by adjusting trimpots in the circuit. Up to 8 channels can be displayed by the circuit using its time multiplexing feature. The character generator was successfully tested in the laboratory but was not included in the underwater demonstration since there were no sensor inputs.

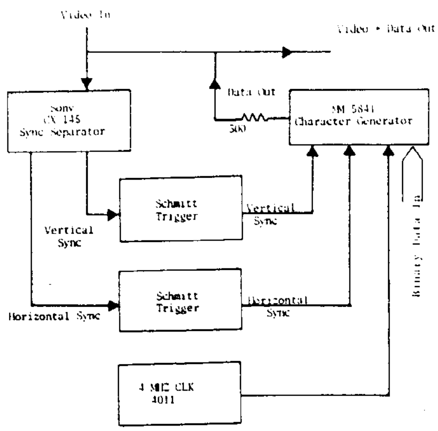


Figure 2. Data superposition circuit

Transmitter and receiver. The transmitter and receiver in the prototype system were a Optelecom 3100TR videolink whose specifications are shown in Table 2. The optical power and detector sensitivity of the Spectronic components contained in the link were enough to provide a predicted conservative margin of 3 dB for a 1 Km link. Equally important for this application was the conservative power requirements for the camera which had to operate underwater on batteries. While rated as drawing 100 ma at 5 volts it was measured in the laboratory that the video output did not degrade until the current was limited to 40 ma or the supply voltage dropped below 3 volts.

Table 2. Optelecom 3100TR Video Link Specifications

Transmitter	
Signal Input	1v p-p, 75Ω
Frequency Range	6 Hz to 16 MHz
Power	5 V.D.C. at 100 ma
Optical Output	20 dB into 200 μm core
Wave Length	820 nm
Temperature Range	-20 to +70°C
Receiver	
Signal Output	1v p-p into 75Ω
Gain (Adjustable Range)	12 dB
Frequency Response	6 Hz to 6 MHz
Peak Signal to RMS Noise	48 dB at 3 dB input
Power	12 V.D.C. at 50 ma
Temperature Range	-20 to +70°C

Fiber link. Lacking access to underwater cable samples two shorter fibers were tested in the link. For laboratory evaluation of the system a 300 m length of ITT T-101 fiber was used. This plastic jacketed step-index glass fiber has a core of 50 μm, an overall diameter of 500 μm and a loss of 5 dB/Km. For the underwater tests a 60 m section of ITT T-203 fiber was used. This graded-index glass fiber has a 50 μm core, an outside diameter of 500 μm and losses of 6 dB/Km. Both fibers were terminated with Amphenol connectors with average losses of 1 dB per connector.

Pressure Housing. The camera, transmitter, 8 "D" cells and 3 "C" cells were installed in an Aqua Craft underwater light housing. This housing is a single piece cast-aluminum housing with a 3/8 inch thick plexiglass faceplate. An external magnetic switch controls the power. The housing was drilled at one end for insertion of the fiber optic bulkhead penetrator. Figure 3 shows the housing configuration.

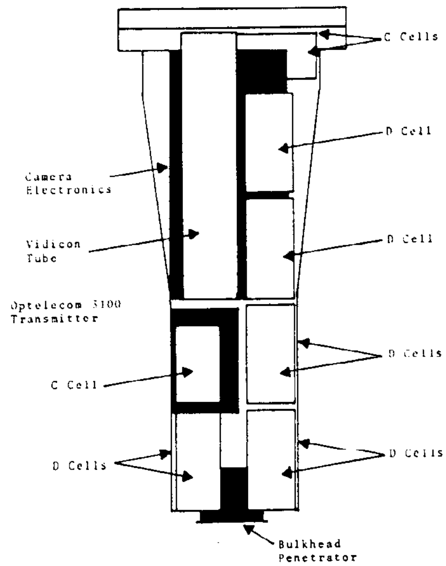


Figure 3. Underwater housing layout

Bulkhead Penetrator. Lacking commercial fiber optic pressure bulkhead penetrators, a simple design was implemented. Most bulkhead penetrator designs [4] that are suitable for use from shallow to moderate depths rely on epoxy for its strength, workability, short term immunity to seawater and low water absorption. Additionally epoxy bonds well to metal and glass providing the capability for a workable watertight seal. The penetrator designed for this system (Figure 4) consists of a threaded bolt whose head was machined to accept an "O" ring. The bolt is fitted into an oversize hole (large enough to pass the fiber connector through) in the pressure hull and tightened by a nut on the interior. The center of the bolt is drilled to a diameter of .7 mm in order to accommodate the passage of the 500 μm fiber. The bolt is countersunk at center to provide additional surface for adhesion. The fiber was epoxied into place with Epotek 377 epoxy using a hypodermic syringe. The potting time was 24 hours, allowing air bubbles to escape. A silicone bead was applied to each end of the seal prior to potting to hold the fiber in place.

Monitor and video tape recorder. A Quasar receiver (companion to the camera) and Sony video tape recorder were used to display and record the video. These were powered by a 12 volt source.

Bidirectional couplers. The engineering design of the system included the margin for bidirectional couplers to be added to the system. Two couplers were obtained from Kaptron, Inc. with losses of 4 dB (optical power out relative to optical power in). A similar loss applies to light traveling to the receiver introducing a total 8 dB loss in a link incorporating two such devices. These couplers work by using parabolic mirrors to split the signal into the source and receiver channels. These added losses would produce a barely adequate margin for a 1 Km link using the chosen source/receiver combination. Longer links would require a more powerful source and/or a more sensitive receiver. Due to the inability to obtain connectors for the pigtails from the couplers, the couplers were not experimentally implemented in the system.

Testing and Performance

The prototype link and a companion link using discrete sources and detectors were tested and evaluated in the laboratory using 55 m and 300 m fibers. Table 3 provides a comparison

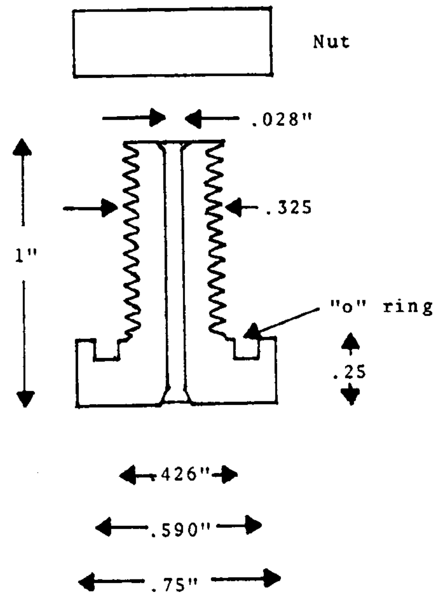


Figure 4. Schematic of bulkhead penetrator

Table 3. LED Insertion (50 μm Core) Powers

LED	Fiber Length (m)	Fiber Attenuation (dB)	Measured Power (dB)	Calculated Insertion Power (dB)	Average Power (dB)
Spectronics SE 3352	55	0.3	13.6	13.9	14.0
	500	1.5	12.7	14.2	
Laser Diode Pigtail IRE 160FB		0.0	17.6		
	55	0.3	15.8	16.1	16.1
	500	1.5	14.6	16.1	

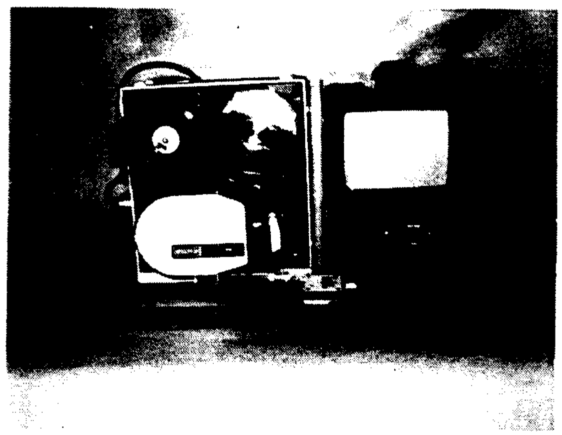
of the calculated and measured power inserted into the cables. Video in both links was of extremely high quality.

The penetrator design was evaluated by lowering four test penetrators to depths of 500, 1000, 3000 and 5000 feet respectively for two hours in Monterey Bay. No evidence of breakdown or catastrophic failure was noted nor was there any visual presence of moisture inside the test containers.

Power tests were conducted to evaluate the ability to operate off of batterypower. The camera/transmitter combination ran off alkaline cells in excess of one hour before reducing the voltage below the volt level specified for the camera.

The complete system (Figure 5) was tested in 50 feet of water in Monterey Bay at a survey site maintained by the Oceanography Department of the Naval Postgraduate School. Natural lighting from an overcast sky provided sufficient light for high quality images even under ledges and rock formations. Approximately 25 minutes of video tape data was obtained. The camera and fiber were exceptionally easy to handle. No difficulty in the payout or recovery of the fiber was encountered. The exceptional light weight of the fiber allowed divers complete freedom of motion without restriction. The fiber was resiliant enough to allow disentanglement from rocks and kelp. The camera and fiber required no more effort than handling an underwater flashlight. The weather conditions included 10-15 knots of wind, a 3 foot swell and a bottom surge that moved the divers two or three feet.

Underwater Camera, 55m Optical
Fiber on Reel



Video Tape Recorder, Monitor
Optelecom 3100R Receiver

Figure 5. Prototype for underwater testing

Summary

An underwater video uplink has been designed and tested in 15 m of water. The 15 m depth test revealed no restriction that would limit further depth extension. Operation should be good to the ultimate depth limit of diver capability. The design has included the transmitter-receiver link, a high pressure hull penetrator and an evaluation of the properties of underseas cables that would ultimately be incorporated into the system.

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